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Interactive key

A visual identification key utilizing both gestalt and analytic approaches to identification of Carices present in North America (Plantae, Cyperaceae)

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Abstract

Images are a critical part of the identification process because they enable direct, immediate and relatively unmediated comparisons between a specimen being identified and one or more reference specimens. The Carices Interactive Visual Identification Key (CIVIK) is a novel tool for identification of North American *Carex* species, the largest vascular plant genus in North America, and two less numerous closely-related genera, *Cymophyllus* and *Kobresia*. CIVIK incorporates 1288 high-resolution tiled image sets that allow users to zoom in to view minute structures that are crucial at times for identification in these genera. Morphological data are derived from the earlier *Carex* Interactive Identification Key (CIIK) which in turn used data from the *Flora of North America* treatments. In this new iteration, images can be viewed in a grid or histogram format, allowing multiple representations of data. In both formats the images are fully zoomable.

Keywords

Visual key, identification, *Carex*, *Cymophyllus*, *Kobresia*, interactive identification, sedges

Introduction

The last ten years may be remembered for the rebirth of plant taxonomy and systematics in a new guise, computational biodiversity informatics. For much of the earth, and North America in particular, botanical information that once required substantial effort to acquire is now reliably provided in seconds by such websites as the Global Biodiversity Information Facility (GBIF), Flora of North America, Missouri Botanical Garden's Tropicos, Encyclopedia of Life, United States Plants Database, and emerging regional herbarium networks. Plant biodiversity is now literally at everyone's fingertips.

State of the art plant identification systems

Traditional biological identification systems today are of two primary types; analytic and gestalt (K. Thiele, pers. comm. 2013). Two forms of analytic keys commonly used today are dichotomous and interactive matrix-based keys. Both are primarily text-based question systems that can yield static images upon the final determination. Conversely, gestalt keys, use an identifiable image of the organism in question. Similar to what is seen in field guides.

Analytic matrix-based keys are considered to be state of the art today The University Of Queensland 2006 due to their ability to scale up across hundreds of taxa. To use, users select characters to achieve a determination of the unknown taxon using a four-panel informational interface. The information panels often represented are 'characters available', 'characters chosen', 'entities available', and entities discarded'. Within this format, it is possible to insert thumbnail-sized, static images to accompany the text if the taxa numbers are relatively small (< 100). But when taxa numbers are higher (>100), their inclusion results in the information panel becoming too long to be usable, e.g. the Carices used here would require copious scrolling across its many meters of length.

Visual keys borrow from both gestalt and analytic methods. They use character matrices for initial pruning of the image set analytically. After a few characters choices the many hundreds of small images are reduced to a manageable set of bigger images. Now gestalt methods take over as the images become larger and truly informative. With this hybrid of functionality, featuring the best of both gestalt and analysis, a novel identification method is created that can cater to the neophyte as well as the expert.

Carex, Kobresia, and Cymophyllous: a model for scalability

Carex is the largest vascular plant genus in North America (Ball and Reznicek 2002). With two closely related genera, *Kobresia* and *Cymophyllus*, it forms the Carices of North America; all three are members of the family *Cyperaceae*, commonly called sedges but often erroneously referred to as grasses. These three genera share a number of basic morphological characteristics including having linear leaves and a fruit enclosed in a bag-

like structure called a perigynium. All have small flowers that lack large, colorful petals and sepals. Plus they share one other important characteristic: they are difficult to identify. Nevertheless, they are morphologically distinct and relatively easily recognizable as a group.

The new visual key

The data used in this project are primarily derived from an interactive identification program to *Carex* that has been online since 2006 at both Utah State University and Louisiana State University (http://www.herbarium.lsu.edu/keys/carex/carex.html). During this time it has been consistently revised and is currently in version 21. (Suppl. materials 3, 4). Web statistics have been tracked from 2007. Data show that numerous individuals worldwide, government agencies, students in classrooms, and participants in identification workshops have repeatedly used the keys. Many users have graciously suggested revisions and clarifications that have increased their usability and performance. The key presented here reflects contributions from several individuals, innumerable field trips, and countless hours in herbaria both identifying and imaging specimens. It is only with such collaboration and effort that an image key to such a large genus can be created.

Goals

My goal in this project was to create an easy to use identification resource that maximized the value of high resolution images while enabling users to explore the distribution of morphological diversity within the genera. Query-able images. For example, to answer questions such as: how are species with trigonous achenes geographically distributed across Canada by province or territory? How common are species with two-sided achenes in species with leaf blades more than 10 mm wide? These sorts of hypotheses are easily answered in histogram mode Fig. 4. Because for the first time, side-by-side image comparisons are possible across species permitting comparative examination and discrimination among closely-related members of any complex, of which there are many, within the Carices. CIVIK is seen here: http://www.herbarium2.lsu.edu/aba/

Project description

Title: Development of visual identification tool

Study area description: This key is designed for use in North America, including Mexico. The original descriptive data was derived from Flora of North America (Ball and Reznicek 2002) and (Mackenzie 1940). My images come from fieldwork focused in eastern North America while other individuals have contributed images from other locations across North America.

Design description:

1. IMAGES

1.1. Contributors

Steve Matson and Tony Reznicek both sent a DVD copy of their *Carex* field images. Lowell Urbatsch contributed his teaching-microscopy-images (http://www.herbarium.lsu.edu/keys/eee/b52.html). My images were collected from many field sites primarily in the north-eastern United States. The New York Botanical Garden Press granted the use of the plates of both North American Cariceae volumes (Mackenzie 1940). The remaining images were found on the World Wide Web (WWW) and their owners (Forest Starr, Kim Starr, Nhy Nyugen, Ann Debolt) contacted by email to request permission for their use. The remaining image contributor, Robert Mohlenbrock, had made the image used here available on http://www.plants.usda.gov/ so it could be used without seeking permission.

1.2. Processing of images

To manage the large image numbers (e.g., Matson hundreds of images; Jones, many thousands), each set of images from each owner was segregated on a local drive. Predictably, across this many image contributors, naming conventions differed greatly, thus significant renaming of image files was required. The basic convention used was to include the taxon name, type of image, and the author in the file name. Another issue of note was the fact that many of these images had been prepared for delivery via the WWW, and had been re-sized. Larger file sizes were selected for inclusion while those that were originally designed as thumbnails were not used. Rarely, older images that were scanned from slides were either cropped or otherwise manipulated with Photoshop CS 3. Lastly, rotation of images for appropriate orientation was also often required.

1.2.1 Image sizes

Image sizes are variable and range from 40 K to over 13 MB. Line drawings and most images by Jones are at 2848 × 4288 with a maximal bit depth of 24. Matson's images were more variable as some images had been prepared for web use. They range from 2592 × 3888 to 550 × 689 with variable bit depths. Other contributed images are of intermediate sizes.

1.3. Imaging of Mackenzie's plates

New York Botanical Garden Press gave permission to image the plates in K. K. Mackenzie's two volume treatment of Carices of North America (Mackenzie 1940) for use in this project. All plates were imaged with a traditional copy stand, using a Nikon 300D camera with a 1:1 macro lens, and two halogen desk lamps for illumination using JPEG format. All images required batch-processing in Photoshop CS3 for color and a minor defect in skew. Additionally, to limit total file size of the project, the images were reduced to approximately one megabyte from three megabytes by resizing.

2. DATA FOR CXML CREATION

2.1. Primary data via export

The dataset was derived from an export of CIIK (http://www.herbarium.lsu.edu/keys/carex/carex.html) in comma separated values (CSV) from LUCID 3.4 Identification Software (The University Of Queensland 2006). These data were the template for the new secondary dataset (Fig. 1). The exported data were imported into Excel 2010 and the Excel PivotViewer plug-in generated the Commerce eXtensible Markup Language (CXML) version of the data (Suppl. material 1). This plugin has since been deprecated in favor of a command line tool, Pauthor (Microsoft 2010a, Microsoft 2010b).

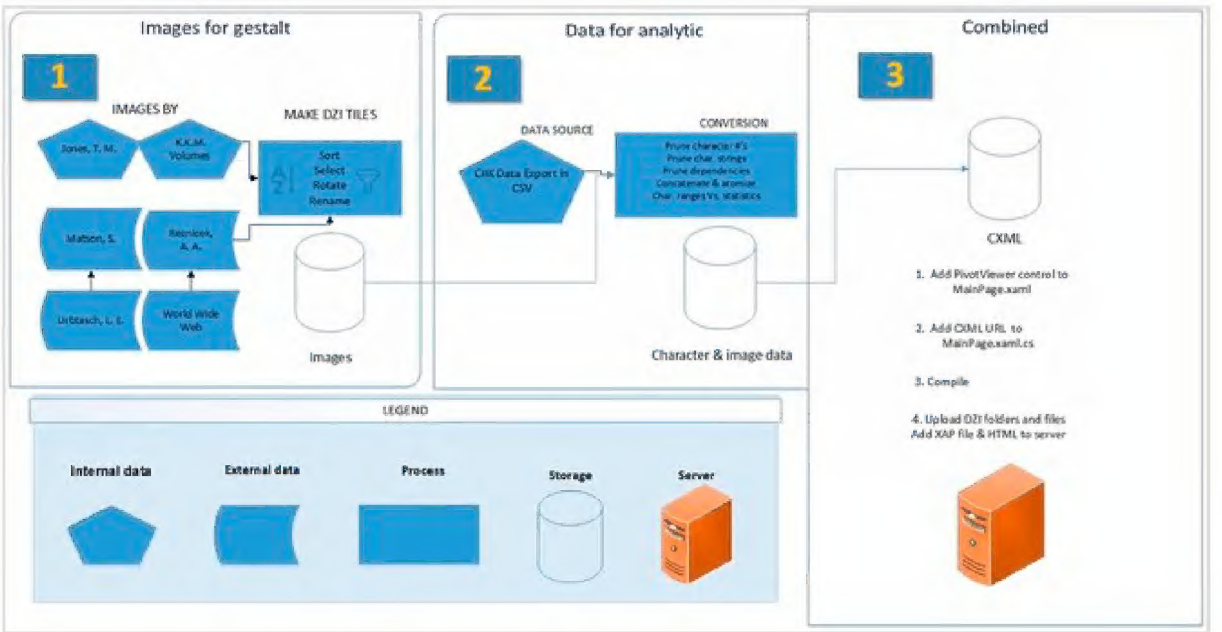

Figure 1.

Workflow of project

2.2. Dependent software

.NET Framework (Microsoft 2007)

Visual Studio 2010 / 2012

Silverlight 4 Tools for Visual Studio 2010

Silverlight Software Development Kit (SDK)

Silverlight 4 Toolkit

PivotViewer SDK

2.3. Interface considerations in a micro-ontology

In Pivot Viewer with the Silverlight 4 format, the characters and states (C&S) are located in the searchable information pane on left, with the displayable information pane on right. This left pane is of a fixed width, lacking word-wrapping functions (Fig. 2). If all C&S

information data mined were used, extensive scrolling would be required and thereby reduce the usability of the key. For this reason, long text strings in the C&S were edited for brevity. A 'less is more' approach was taken, with C&S being restricted to those that would be appropriate in an ontology.

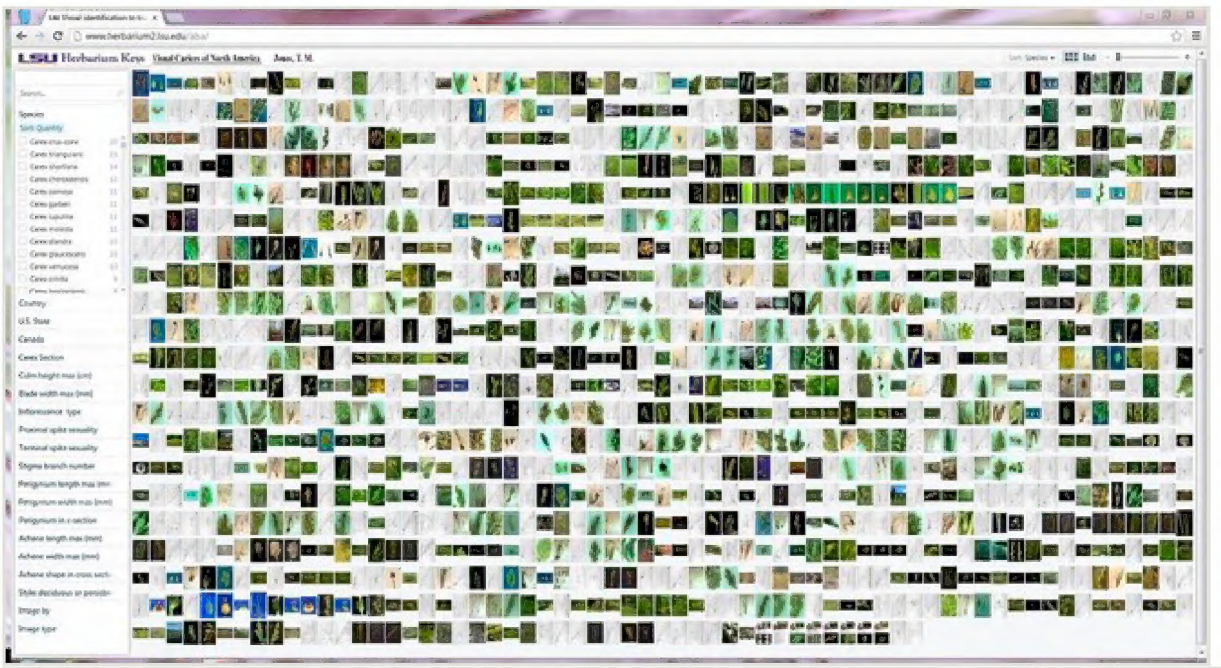

Figure 2.

The Visual Carices of North America upon instantiation in default grid setting.

2.4. Clustering issues in the graphical mode require a “normalization character state”

Visual keys require a normalization character state; or the image numbers must be standardized for graphical display

If image numbers between species are not consistent, a representative or semantic image is required. This leading image permits true one-to-one comparisons over any number of taxa. Without it, accurate representations of the data would be obscured due to clustering. For this reason, only those taxa with a line drawing are presented here to allow for a one-to-one comparison across taxa. It was done early in development as a work-around to the differing number of images per taxon problem. Later unpublished works of this type deal with this issue in multiple ways (see 'Additional information').

To use this normalization feature, select ‘Image by’ at the base of the left information pane, then select ‘Mackenzie, K. K.’ from the information panel. Now, only grey scale images are used in a portrait format with an attention to the aspect ratio. All images are presented in the same fashion and uniformity in a grey scale that is easy to visually interpret. This ad-hoc commitment to Mackenzie's species list was done for this reason.

2.5. Data and images together

Images were added in small batches in a new Excel file. Character data were copy-pasted from the secondary spreadsheet to the third instance of Excel to form the final building file across multiple monitors.

2.6. Tertiary data

The completed third spreadsheet is now run using the 'New collection tool' by selecting its icon in the ribbon panel of Excel. It generates two primary products; image tiles in numerous folders and a CXML file (Suppl. material 1). The control leverages Deepzoom technology (Microsoft 2008) to create a deep zoom image library (DZI) and deep zoom collection files (DZC) like those seen on Google or Bing maps (Fig. 3). This geometric series of images supports the zoom-ability of images. As the user zooms in, things get geometrically resolved without the penalty associated with a large image download. As users pan through a collection, they can see only what they desire.

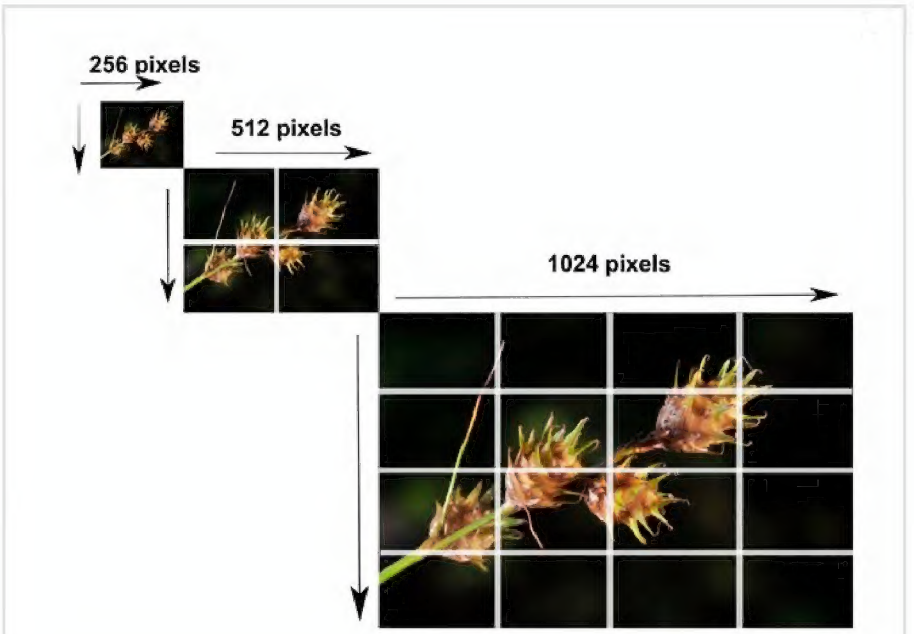

Figure 3.

Tiled image set illustrating the change in file size as well as number of images by creating a geometric series of images

2.6.1 Issues completing tertiary data for image tiles and CXML

Hardware and software issues were experienced at all stages. Testing revealed that while tiling a few hundred high resolution images with PivotViewer is manageable, using over a thousand high-resolution images made Excel unstable. Memory allocation as well as the processor spiking issues - limited development time and resulted in extended periods of waiting for test builds overnight or on a build across many days. The creation of the image tiles is best attempted with a state-of-the-art computer with a solid state drive. CIVIK total tile-set and cxml build-time was approximately 12 hours for the final presented build (Fig. 4).

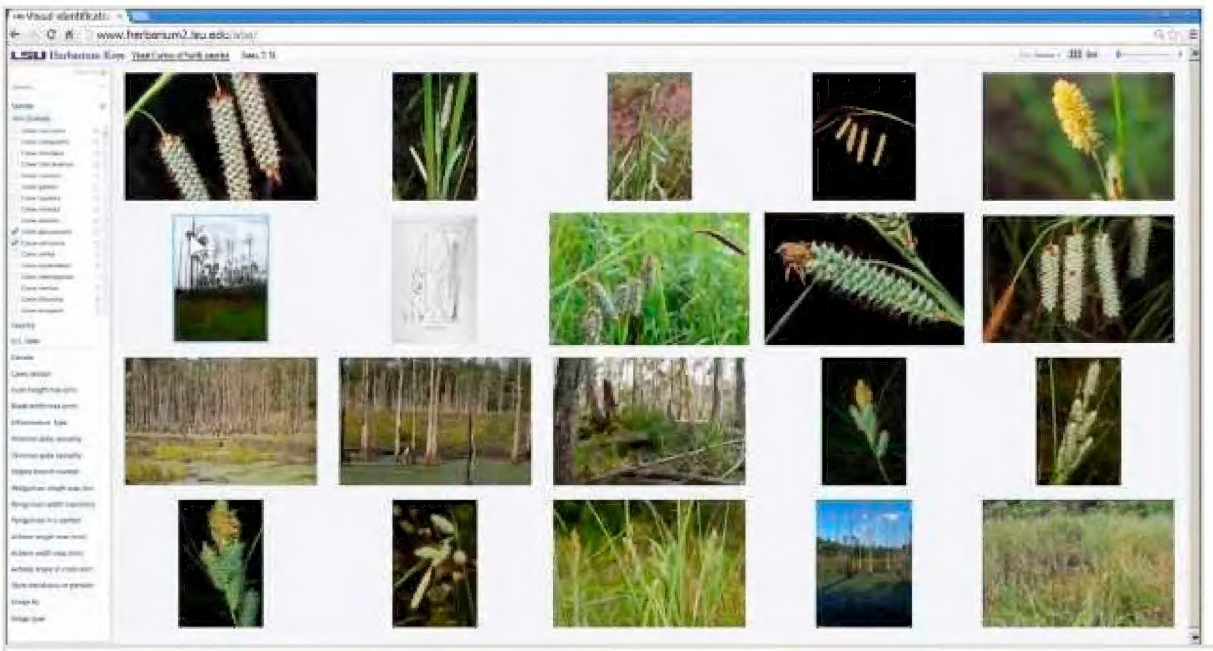

Figure 4.

An Interactive Visual Identification Key to Carices of North America beta version.

3. Deployable image tiles sizes

The DZI files are nearly four gigabytes in file size and comprise over 250,000 image-tile files in over 18,000 folders with an associated CXML of 3.3 megabytes in size. A Silverlight application package (XAP) file is also required to drive the application.

4. Compile with Visual Studio

To compile with Visual Studio, open a new instance of a Silverlight application for the web in Visual Studio. Now add the references to PivotViewer on the main Extensible Application Markup Language (XAML) page in UserControl. Then add the URL to the CXML file to the XAML.CS code behind file. Then, build or compile the deployment package for placement on the server.

4.1 XAML and XAML.CS Code behind Files

See 'software technical features'

5. Deploy to web server

Ensure that the following Multipurpose Internet Mail Extensions (MIME) types are configured on server; significant development time was lost due to one of these settings not being in place.

• CXML - text/xml

• DZC - text/xml

• DZI - text/xml

6. History of Use

CIVIKhas been tracked via Google Analytics with the other later works of visual types. These combined works reveal that 13,933 visits occurred from 116 countries in 2464 cities over a three year period. An average dwell time of two minutes across the three works of type is seen here. (See Additional information and Suppl. material 6).

7. Considerations and discussion

While Silverlight is ideal for this data format, it will be deprecated (see http://support.microsoft.com/gp/lifean45) as no future versions are scheduled for release. It will, however, be supported for ten years which will aid future works of this kind. Thankfully, HTML 5 versions are also now available for PivotViewer that enable the CXML format across all devices in a device agnostic fashion. This cross platform capability is exciting as it does not require the Silverlight runtime, so phone and tablets are enabled as well with HTML 5. HTML 5 versions have one other important advantage - a Google translate function is easily added in minutes to over 70 languages (see http://translate.google.com/about/). Opening the door to future iterations of high-resolution images supported by text that is translatable.

Funding: SLouisiana State University

Geographic coverage

Description: The identification key can be used for species occurring in United States, Canada, and Mexico. Several species have a much wider distribution, hence the key has some value in other regions as well.

Coordinates: 90 and 15 Latitude; -180 and -45 Longitude.

Taxonomic coverage

Taxa included:

Rank	Scientific Name	Common Name
genus	*Carex*	sedge
genus	*Kobresia*	sedge
genus	*Cymophyllus*	sedge
species	*Carex abrupta* Mack.	abruptbeak sedge
species	*Carex abscondita* Mack.	thicket sedge
species	*Carex adusta* Boott	lesser brown sedge
species	*Carex aestivalis* M.A. Curtis ex A. Gray	summer sedge
species	*Carex aggregata* Mack.	glomerate sedge
species	*Carex alata* Torr.	broadwing sedge

species	*Carex albicans* Willd. ex Spreng.	whitetinge sedge
species	*Carex albonigra* Mack.	blackandwhite sedge
species	*Carex albursina* E. Sheld.	white bear sedge
species	*Carex alligata* Boott	Hawai'i sedge
species	*Carex alma* L.H. Bailey	sturdy sedge
species	*Carex alopecoidea* Tuck.	Foxtail sedge
species	*Carex amphibola* Steud.	eastern narrowleaf sedge
species	*Carex amplectens* Mack.	claspbract sedge
species	*Carex amplifolia* Boott	bigleaf sedge
species	*Carex annectens* (E.P. Bicknell) E.P. Bicknell	yellowfruit sedge
species	*Carex anthoxanthea* J. Presl & C. Presl	grassyslope arctic sedge
species	*Carex aperta* Boott	Columbian sedge
species	*Carex aquatilis* Wahlenb.	water sedge
species	*Carex arapahoensis* Clokey	Arapaho sedge
species	*Carex arcta* Boott	northern cluster sedge
species	*Carex arctata* Boott	drooping woodland sedge
species	*Carex arenaria* L.	sand sedge
species	*Carex arkansana* (L.H. Bailey) L.H. Bailey	Arkansas sedge
species	*Carex assiniboinensis* W. Boott	Assiniboia sedge
species	*Carex atherodes* Spreng.	wheat sedge
species	*Carex athrostachya* Olney	slenderbeak sedge
species	*Carex atlantica* L. H. Bailey	prickly bog sedge
species	*Carex atrata* L.	black scale sedge
species	*Carex atratiformis* Britton	scrabrous black sedge
species	*Carex atrofusca* Schkuhr	darkbrown sedge
species	*Carex atrosquama* Mack.	lesser blackscale sedge
species	*Carex aurea* Nutt.	golden sedge
species	*Carex austrina* Mack.	southern sedge
species	*Carex austrocaroliniana* L.H. Bailey	tarheel sedge
species	*Carex aztecica* Mack.	Aztec sedge
species	*Carex backii* Boott	Back's sedge
species	*Carex baileyi* Britton	Bailey's sedge
species	*Carex baltzellii* Chapm.	Baltzell's sedge
species	*Carex barrattii* Torr. ex Schwein.	Barratt's sedge
species	*Carex bebbii* (L. H. Bailey) Olney ex Fernald	Bebb's sedge
species	*Carex bella* L.H. Bailey	southwestern showy sedge
species	*Carex bicknellii* Britton & A.Br.	Bicknell's sedge
species	*Carex bicolor* Bellardi ex All.	two-color sedge
species	*Carex bigelowii* Torr. ex Schwein.	Bigelow's sedge
species	*Carex biltmoreana* Mack.	stiff sedge
species	*Carex blanda* Dewey	eastern woodland sedge
species	*Carex bolanderi* Olney	Bolander's sedge
species	*Carex boliviensis* Van Heurck & Müll. Arg.	Bolivian sedge

species	*Carex breweri* Boott	Brewer's sedge
species	*Carex brizoides* L.	
species	*Carex bromoides* Willd.	brome-like sedge
species	*Carex brunnescens* (Pers.) Poir.	brownish sedge
species	*Carex bullata* Willd.	button sedge
species	*Carex bushii* Mack.	Bush's sedge
species	*Carex buxbaumii* Wahlenb.	Buxbaum's sedge
species	*Carex californica* L.H. Bailey	California sedge
species	*Carex canescens* L.	silvery sedge
species	*Carex capillaris* L.	hair-like sedge
species	*Carex capitata* Sol.	capitate sedge
species	*Carex careyana* Torr. ex Dewey	Carey's sedge
species	*Carex caroliniana* Schwein.	Carolina sedge
species	*Carex caryophyllea* Latourr.	vernal sedge
species	*Carex castanea* Wahlenb.	chestnut sedge
species	*Carex cephaloidea* (Dewey) Dewey ex Boott	thinleaf sedge
species	*Carex cephalophora* Muhl. ex Willd.	oval-leaf sedge
species	*Carex cherokeensis* Schwein.	Cherokee sedge
species	*Carex chihuahuensis* Mack.	Chihuahuan sedge
species	*Carex chordorrhiza* L.	creeping sedge
species	*Carex circinnata* C.A.Mey.	coiled sedge
species	*Carex collinsii* Nutt.	Collins' sedge
species	*Carex communis* L.H. Bailey	fibrousroot sedge
species	*Carex comosa* Boott	longhair sedge
species	*Carex complanata* Torr. & Hook.	hirsute sedge
species	*Carex concinna* R. Br.	low northern sedge
species	*Carex concinnoides* Mack.	northwestern sedge
species	*Carex conjuncta* Boott	soft fox sedge
species	*Carex conoidea* Willd.	openfield sedge
species	*Carex crawei* Dewey ex Torr.	Crawe's sedge
species	*Carex crawfordii* Fernald	Craweford's sedge
species	*Carex crebriflora* Wiegand	coastal plain sedge
species	*Carex crinita* Lam.	fringed sedge
species	*Carex cristatella* Britton & A.Br.	crested sedge
species	*Carex crus-corvi* Shuttlew. ex Kunze	ravenfoot sedge
species	*Carex cryptolepis* Mack.	northeastern sedge
species	*Carex cumulata* (L.H. Bailey) Mack.	clustered sedge
species	*Carex cusickii* Mack.	Cusick's sedge
species	*Carex dasycarpa* Muhl.	sandywoods sedge
species	*Carex davisii* Schwein. & Torr.	Davis' sedge
species	*Carex davyi* Mack.	Davy's sedge
species	*Carex debilis* Michx.	white edge sedge
species	*Carex decomposita* Muhl.	cypressknee sedge

species	*Carex deflexa* Hornem.	northern sedge
species	*Carex densa* (L.H. Bailey) L.H. Bailey	dense sedge
species	*Carex deweyana* Schwein.	Dewey's sedge
species	*Carex diandra* Schrank	lesser panicled sedge
species	*Carex digitalis* Willd.	slender woodland sedge
species	*Carex donnell-smithii* L.H. Bailey	Donell's sedge
species	*Carex douglasii* Boott	Douglas' sedge
species	*Carex ebenea* Rydb.	ebony sedge
species	*Carex eburnea* Boott	bristleleaf sedge
species	*Carex egglestonii* Mack.	Eggleston's sedge
species	*Carex elliottii* Schwein. & Torr.	Elliott's sedge
species	*Carex elynoides* Holm	blackroot sedge
species	*Carex emoryi* Dewey	Emory's sedge
species	*Carex engelmannii* L.H. Bailey	Engelmann's sedge
species	*Carex exilis* Dewey	coastal sedge
species	*Carex exsiccata* L.H. Bailey	western inflated sedge
species	*Carex festucacea* Schkuhr ex Willd.	fescue sedge
species	*Carex feta* L. H. Bailey	greensheath sedge
species	*Carex filifolia* Nutt.	threadleaf sedge
species	*Carex fissa* Mack.	hammock sedge
species	*Carex flacca* Schreb.	heath sedge
species	*Carex flaccosperma* Dewey	thinfruit sedge
species	*Carex flava* L.	yellow sedge
species	*Carex floridana* Schwein.	Florida sedge
species	*Carex foenea* Willd.	dry-spike sedge
species	*Carex folliculata* L.	norther long sedge
species	*Carex formosa* Dewey	handsome sedge
species	*Carex fracta* Mack.	fragile sheath sedge
species	*Carex frankii* Kunth	Frank's sedge
species	*Carex garberi* Fernald	elk sedge
species	*Carex geophila* Mack.	White Mountain sedge
species	*Carex geyeri* Boott	Geyer's sedge
species	*Carex gigantea* Rudge	giant sedge
species	*Carex glacialis* Mack.	glacial sedge
species	*Carex glareosa* Schkuhr ex Wahlenb.	lesser salt marsh sedge
species	*Carex glaucescens* Elliott	southern waxy sedge
species	*Carex glaucodea* Tuck. ex Olney	blue sedge
species	*Carex globosa* Boott	roundfruit sedge
species	*Carex gmelinii* Hook. & Arn.	Gmelin's sedge
species	*Carex gracillima* Schwein.	graceful sedge
species	*Carex granularis* Muhl. ex Willd.	limestone meadow sedge
species	*Carex gravida* L.H. Bailey	heavy sedge
species	*Carex grayi* J. Carey	Gray's sedge

species	*Carex grisea* Wahlenb.	inflated narrow-leaf sedge
species	*Carex gynandra* Schwein.	nodding sedge
species	*Carex gynocrates* Wormsk.	northern bog sedge
species	*Carex gynodynama* Olney	Olney's hairy sedge
species	*Carex halliana* L.H. Bailey	Hall's sedge
species	*Carex hallii* Olney	deer sedge
species	*Carex harfordii* Mack.	Harford's sedge
species	*Carex hassei* L.H. Bailey	salt sedge
species	*Carex haydenii* Dewey	Hayden's sedge
species	*Carex helleri* Mack.	Heller's sedge
species	*Carex hendersonii* L. H. Bailey	Henderson's sedge
species	*Carex heteroneura* S.Watson	different-nerve sedge
species	*Carex hirsutella* Mack.	fuzzy sedge
species	*Carex hirta* L.	hammer sedge
species	*Carex hirtifolia* Mack.	pubescent sedge
species	*Carex hirtissima* W. Boott	fuzzy sedge
species	*Carex hitchcockiana* Dewey	Hitchcock's sedge
species	*Carex holostoma* Drejer	arctic marsh sedge
species	*Carex hoodii* Boott	Hood's sedge
species	*Carex hookeriana* Dewey	Hooker's sedge
species	*Carex hormathodes* Fernald	marsh straw sedge
species	*Carex houghtoniana* Torr. ex Dewey	Houghton's sedge
species	*Carex hyalina* Boott	tissue sedge
species	*Carex hyalinolepis* Steud	shoreline sedge
species	*Carex hystericina* Muhl. ex Willd.	bottlebrush sedge
species	*Carex idahoa* L. H. Bailey	Idaho sedge
species	*Carex illota* L. H. Bailey	sheep sedge
species	*Carex incurviformis* Mack.	coastal sand sedge
species	*Carex inops* L. H. Bailey	long-stolon sedge
species	*Carex integra* Mack.	smoothbeak sedge
species	*Carex interior* L. H. Bailey	inland sedge
species	*Carex interrupta* Boeckeler	greenfruit sedge
species	*Carex intumescens* Rudge	greater bladder sedge
species	*Carex jamesii* Schwein.	James' sedge
species	*Carex jonesii* L.H. Bailey	Jones' sedge
species	*Carex joorii* L.H. Bailey	cypress swamp sedge
species	*Carex lacustris* Willd.	hairy sedge? (lake sedge)
species	*Carex laeviculmis* Meinsh.	smoothstem sedge
species	*Carex laxiculmis* Schwein.	spreading sedge
species	*Carex laxiflora* Lam.	broad looseflower sedge
species	*Carex leavenworthii* Dewey	Leavenworth's sedge
species	*Carex lemmonii* W. Boott	Lemmon's sedge
species	*Carex lenticularis* Michx.	lakeshore sedge

species	*Carex leporinella* Mack.	Sierra hare sedge
species	*Carex leptalea* Wahlenb.	bristlystalked sedge
species	*Carex leptonervia* (Fernald) Fernald	nerveless woodland sedge
species	*Carex limosa* L.	mud sedge
species	*Carex livida* (Wahlenb.) Willd.	livid sedge
species	*Carex loliacea* L.	ryegrass sedge
species	*Carex lonchocarpa* Willd. ex Spreng.	southern long sedge
species	*Carex longii* Mack.	Long's sedge
species	*Carex louisianica* L. H. Bailey	Louisiana sedge
species	*Carex lucorum* Willd.	Blue Ridge sedge
species	*Carex lupuliformis* Sartwell ex Dewey	false hop sedge
species	*Carex lupulina* Muhl. ex Willd.	hop sedge
species	*Carex lurida* Wahlenb.	shallow sedge
species	*Carex luzulina* Olney	woodrush sedge
species	*Carex lyngbyei* Hornem.	Lyngbye's sedge
species	*Carex macloviana* d'Urv.	thickhead sedge
species	*Carex macrocephala* Willd. ex Spreng.	largehead sedge
species	*Carex macrochaeta* C. A. Mey.	longawn sedge
species	*Carex marina* Dewey	sea sedge
species	*Carex mariposana* L.H. Bailey ex Mack.	Mariposa sedge
species	*Carex meadii* Dewey	Mead's sedge
species	*Carex membranacea* Hook.	fragile sedge
species	*Carex merritt-fernaldii* Mack.	Fernald's sedge
species	*Carex mertensii* Prescott ex Bong.	Mertens' sedge
species	*Carex michauxiana* Boeckeler	Michaux's sedge
species	*Carex microdonta* Torr.	littletooth sedge
species	*Carex microglochin* Wahlenb.	fewseeded bog sedge
species	*Carex micropoda* C. A. Mey.	
species	*Carex microptera* Mack.	small wing sedge
species	*Carex misera* Buckley	wretched sedge
species	*Carex mitchelliana* M. A. Curtis	Mitchell's sedge
species	*Carex molesta* Mack.	troublesome sedge
species	*Carex muehlenbergii* Willd.	Muehlenberg's sedge
species	*Carex multicaulis* L.H. Bailey	manystem sedge
species	*Carex multicostata* Mack.	manyrib sedge
species	*Carex muricata* L.	rough sedge
species	*Carex muskingumensis* Schwein.	Muskingum sedge
species	*Carex nebraskensis* Dewey	Nebraska sedge
species	*Carex nervina* L.H. Bailey	Sierra sedge
species	*Carex neurophora* Mack.	alpine nerve sedge
species	*Carex nigromarginata* Schwein.	black edge sedge
species	*Carex normalis* Mack.	greater straw sedge
species	*Carex norvegica* Retz.	Norway sedge

species	*Carex nudata* W. Boott	naked sedge
species	*Carex obnupta* L. H. Bailey	slough sedge
species	*Carex obtusata* Lilj.	obtuse sedge
species	*Carex occidentalis* L. H. Bailey	western sedge
species	*Carex oligosperma* Michx.	fewseed sedge
species	*Carex oreocharis* Holm	grassyslope sedge
species	*Carex ormostachya* Wiegand	necklace spike sedge
species	*Carex oxylepis* Torr. & Hook.	sharpscale sedge
species	*Carex paleacea* Schreb. ex Wahlenb.	chaffy sedge
species	*Carex pallescens* L.	pale sedge
species	*Carex panicea* L.	grass-like sedge
species	*Carex pansa* L.H. Bailey	Payson's sedge
species	*Carex pauciflora* Lightf.	fewflower sedge
species	*Carex peckii* Howe	Peck's sedge
species	*Carex pedunculata* Muhl. ex Willd.	longstalk sedge
species	*Carex pellita* Muhl ex Willd.	wooly sedge
species	*Carex pensylvanica* Lam.	Pensylvania sedge
species	*Carex perglobosa* Mack.	globe sedge
species	*Carex petricosa* Dewey	rockdwelling sedge
species	*Carex phaeocephala* Piper	dunhead sedge
species	*Carex picta* Steud.	Boott's sedge
species	*Carex pityophila* Mack.	loving sedge
species	*Carex planostachys* Kunze	cedar sedge
species	*Carex plantaginea* Lam.	plantainleaf sedge
species	*Carex platyphylla* J. Carey	broadleaf sedge
species	*Carex podocarpa* R. Br.	shortstalk sedge
species	*Carex polystachya* Sw. ex Wahlenb.	Caribbean sedge
species	*Carex praeceptorium* Mack.	early sedge
species	*Carex praegracilis* W. Boott	clustered field sedge
species	*Carex prairea* Dewey ex Alph.Wood	prairie sedge
species	*Carex prasina* Wahlenb.	drooping sedge
species	*Carex praticola* Rydb.	meadow sedge
species	*Carex preslii* Steud.	Presl's sedge
species	*Carex projecta* Mack.	necklace sedge
species	*Carex proposita* Mack.	Great Smoky Mountain sedge
species	*Carex pseudocyperus* L.	cypress-like sedge
species	*Carex purpurifera* Mack.	purple sedge
species	*Carex radiata* (Wahlenb.) Small	eastern star sedge
species	*Carex rariflora* (Wahlenb.) Sm.	looseflower alpine sedge
species	*Carex raynoldsii* Dewey	Raynolds' sedge
species	*Carex recta* Boott	estuary sedge
species	*Carex reniformis* (L.H. Bailey) Small	kidneyshape sedge
species	*Carex retroflexa* Muhl. ex Willd.	reflexed sedge

species	*Carex rosea* Willd.	rosy sedge
species	*Carex rossii* Boott	Ross' sedge
species	*Carex rostrata* Stokes	beaked sedge
species	*Carex rufina* Drejer	snowbed sedge
species	*Carex rupestris* All.	curly sedge
species	*Carex sartwellii* Dewey	Sartwell's sedge
species	*Carex saxatilis* L.	rock sedge
species	*Carex scabrata* Schwein.	eastern rough sedge
species	*Carex scabriuscula* Mack.	Siskiyou sedge
species	*Carex schweinitzii* Dewey ex Schwein.	Schweinitz's sedge
species	*Carex scirpoidea* Michx.	northern singlespike sedge
species	*Carex scoparia* Willd.	broom sedge
species	*Carex scopulorum* Holm	mountain sedge
species	*Carex senta* Boott	swamp carex
species	*Carex seorsa* Howe	weak stellate sedge
species	*Carex shortiana* Dewey & Torr.	Short's sedge
species	*Carex simulata* Mack.	analogue sedge
species	*Carex socialis* Mohlenbr. & Schwegman	low woodland sedge
species	*Carex sparganioides* Muhl. ex Willd.	bur-reed sedge
species	*Carex specifica* L.H. Bailey	narrowfruit sedge
species	*Carex spectabilis* Dewey	showy sedge
species	*Carex spicata* Huds.	prickly sedge
species	*Carex spissa* L.H.Bailey ex Hemsl.	San Diego sedge
species	*Carex sprengelii* Dewey ex Spreng.	Sprengel's sedge
species	*Carex squarrosa* L.	squarrose sedge
species	*Carex sterilis* Willd.	dioecious sedge
species	*Carex stipata* Muhl. ex Willd.	awlfruit sedge
species	*Carex straminea* Willd. ex Schkuhr	straw sedge
species	*Carex striata* Michx.	Walter's sedge
species	*Carex striatula* Michx.	lined sedge
species	*Carex stricta* Lam.	upright sedge
species	*Carex styloflexa* Buckley	bent sedge
species	*Carex stylosa* C. A. Mey.	variegated sedge
species	*Carex subbracteata* Mack.	smallbract sedge
species	*Carex supina* Willd. ex Wahlenb.	weak arctic sedge
species	*Carex swanii* (Fernald) Mack.	Swan's sedge
species	*Carex sylvatica* Huds.	European woodland sedge
species	*Carex tenera* Dewey	quill sedge
species	*Carex tetanica* Schkuhr	rigid sedge
species	*Carex torreyi* Tuck.	Torrey's sedge
species	*Carex tribuloides* Wahlenb.	blunt broom sedge
species	*Carex tuckermanii* Boott	Tuckerman's sedge
species	*Carex turgescens* Torr.	pine barren sedge

species	*Carex typhina* Michx.	cattail sedge
species	*Carex umbellata* Willd.	parasol sedge
species	*Carex verrucosa* Muhl.	warty sedge
species	*Carex vesicaria* L.	blister sedge
species	*Carex viridula* Michx.	little green sedge
species	*Carex vulpina* L.	true-fox sedge
species	*Carex vulpinoidea* Michx.	fox sedge
species	*Carex willdenowii* Willd.	Willdenow's sedge
species	*Carex woodii* Dewey	Wood's sedge
species	*Carex xerantica* L.H. Bailey	whitescale sedge
species	*Cymophyllus fraseri* (Ker Gawl.) Kartesz & Gandhi	Fraser's cymophyllous
species	*Kobresia simpliciuscula* (Wahlenb.) Mack.	simple bog sedge

Usage rights

Characters used in the key

1. Species
2. Country
3. U.S. state
4. Canadian province or territory
5. Section within Carex
6. Culm height
7. Blade width
8. Inflorescence type
9. Proximal spike sexuality
10. Terminal spike sexuality
11. Stigma branch number
12. Perigynium length
13. Perigynium width
14. Perigynium cross-section shape
15. Achene length
16. Achene width
17. Achene cross-section shape
18. Style: whether deciduous or persistent
19. Image author
20. Image type

Software specification

Name: Carices Interactive Visual Identification Key

Version: 1.1

Interface language: English

Platform: Silverlight runtime

Web location: http://www.herbarium2.lsu.edu/aba/

Software technical features

Main XAML page

```
<UserControl x:Class="A5.MainPage">
  xmlns="http://schemas.microsoft.com/winfx/2006/xaml/presentation"
  xmlns:x="http://schemas.microsoft.com/winfx/2006/xaml"
  xmlns:d="http://schemas.microsoft.com/expression/blend/2008"
  xmlns:mc="http://schemas.openxmlformats.org/markup-compatibility/2006"
  xmlns:local="clr-namespace:System.Windows.Pivot;assembly=System.Windows.Pivot"
  mc:Ignorable="d" d:DesignHeight="300" d:DesignWidth="400" Loaded="UserControl_Loaded">
  <Grid x:Name="LayoutRoot" Background="Black">
  <local:PivotViewer x:Name="Pivot"/>
  </Grid>
</UserControl>
```

XAML.CS or Code behind

```
using System;
using System.Collections.Generic;
using System.Linq;
using System.Net;
using System.Windows;
using System.Windows.Controls;
using System.Windows.Documents;
using System.Windows.Input;
using System.Windows.Media;
using System.Windows.Media.Animation;
using System.Windows.Shapes;
using System.Windows.Pivot;
namespace A10
{
  public partial class MainPage: UserControl
  {
    public MainPage()
    {
      InitializeComponent();
      Pivot.LoadCollection("http://www.herbarium2.lsu.edu/aba/A10.cxml", string.Empty);
    }
    private void UserControl_Loaded(object sender, RoutedEventArgs e)
    {

    }
}
```

Additional information

Later examples of visual keys deal with the clustering problem differently. Both Silverlight and HTML 5 based grass genera of Louisiana keys use existing herbarium specimen images to normalize, one herbarium specimen per taxon. Leveraging recent physical and vetted sources. This normalization character is select-able as 'one-to-one comparisons' at the bottom of character information panel http://www.herbarium2.lsu.edu/grass2/. Secondly, Kingdom Plantae in HTML 5 is normalized by image number only, without a selectable character state, across divisions http://www.herbarium2.lsu.edu/aca/. Magnoliophyta is taken at a log value due to its disparate taxa value when compared to the other divisions.

Acknowledgements

The author sincerely appreciates the ground-breaking work completed by others before this project even began. Without these prior efforts, this current project could not have been completed in this same time-frame. A sincere thank you to all the editors of Flora of North America, Volume 23, and the image contributors. To G. Wilder, J. Bissell, M. Barkworth, A. Reznicek, K. Niklas, and my Ph.D. advisor, L. Urbatsch, thank you for sharing your wisdom and support. Also, I wish to thank W. Thomas and K. Thiele, for editorial commentary provided for this manuscript.

Author contributions

Jones developed the project, and contacted the other contibutors for images. S. Matson and T. Reznicek both mailed a DVD copy of their Carex field images. L. Urbatsch's teaching-microscopy-images were copied and saved to USB thumbdrives. New York Botanical Garden Press permitted the use of the images of both North American Cariceae volumes by Mackenzie, K.K. Remaining image owners were found on the WWW and contacted by email. Thankfully, they granted permission for usage, including; F. Starr & K. Starr, N. Nyugen, and A. Debolt. R. Mohlenbrock's image was gathered from Plants.gov.

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Supplementary materials

Suppl. material 1: Tertiary file structure for Carices CXML file

Authors: Jones, T. M.

Data type: occurences, morphological,

Filename: A10.cxml - Download file (4.19 MB)

Suppl. material 2: Secondary Carex morphology data; cleaned and truncated for building CXML

Authors: Jones, T. M.

Data type: occurrences, morphological, images

Brief description: This file is an example of a build file for the creation of the CXML file.

Filename: 957am fixed scirpoidea space issue.xlsx - Download file (483.24 kb)

Suppl. material 3: Website data from Utah State University

Authors: Google Analytics

Data type: PDF

Brief description: Data sheet for visitiation to CIIK by country

Filename: Analytics utc.usu.edu_keys_Carex_Carex.html Location 20060531-20130630.pdf - Download file (180.01 kb)

Suppl. material 4: Website data from Louisiana State University

Authors: Google Analytics

Data type: PDF

Brief description: Data sheet for visitiation to CIIK by country

Filename: Analytics Carex key LSU Location 20060531-20130630.pdf - Download file (178.08 kb)

Suppl. material 5: Primary Carex morphology data from Lucid 3.4

Authors: Jones, T. M.

Data type: XLSX

Brief description: Export from CIIK 2013 in CSV format

Filename: Carex-all-CSV.xlsx - Download file (732.82 kb)

Suppl. material 6: CIVIK usage 2011 - 2013

Authors: Google Analytics

Data type: PDF

Brief description: This includes all visual keys developed. Here CIVIK is represented by both /aba/ and /aaa/ and iteratives.

Filename: Analytics www.herbarium2.lsu.edu_aaa_A5TestPage.html Pages 20100531-20130630.pdf - Download file (168.54 kb)

Suppl. material 7: Visual keys usage with Google Analytics

Authors: Google

Data type: analytics

Brief description: Compilation of all visual keys using Google Analytics

Filename: Analytics www.herbarium2.lsu.edu-aaa-A5TestPage.html Language 20100809-20130908.pdf - Download file (189.65 kb)